



*Institute of Paper Science and Technology
Atlanta, Georgia*

IPST Technical Paper Series Number 907

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June 2001

**Submitted to
Holzforschung**

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Flake Drying Temperature Affects Mat Properties During Pressing

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Summary

The contact angle of water on wood rises sharply as the wood approaches dryness. The general shape of the rise can be reproduced through thermodynamic calculations that consider the presence of extractives on the surface. SEM work confirms that extractives move progressively to the surface with increasing drying temperature. Other factors such as pore closure also contribute to surface hydrophobicity. The temperature profile within a stack of flakes during accelerated pressing shows a break at 100°C when flakes dried at high temperature are processed. Moisture is known to be driven from the outer layers of the stack to the core during early pressing. If the flake surface is hydrophobic then this moisture would film on the surface rather than penetrate into the flake. Subsequent evaporation of the moisture would lead to high pressure. Hence, flakes dried at high temperature should be more prone to delamination. High-temperature drying also promotes VOC emissions and there should be operational and environmental benefits to drying at lower temperature.

Keywords:

Contact angle

Pressing

Extractives

Delamination

Mechanism

Introduction

Numerous studies have established that the surface of wood is inactivated when overdried. Christiansen (1990, 1991) studied the effect of overdrying on the glue bond. The movement of extractives to the surface, reorientation of molecules on the wood surface, and irreversible closure of large micropores in cell walls were identified as contributing factors. For Southern pine, the movement of extractives during drying was believed to lead to poor wettability. Hemingway (1969) demonstrated the reduction in surface wettability of yellow birchwood after heating, and Yazaki *et al.* (1994) showed that the uneven extractives distribution in blackbutt veneers made high quality bonding difficult to achieve with phenolic adhesives. Jordan and Wellons (1977) showed that commercial drying of veneer damaged the surface, and that extractive content and type had a major effect on wettability. These studies provide ample evidence that drying temperature inactivates the wood surface. In this paper we demonstrate that surface properties also influence the pressure developed in the core during pressing.

Materials and Methods

Green veneer (pine) was obtained from the Georgia-Pacific mill in Madison, GA. Specimens (25.4 x 25.4 x 3.2 mm) were first dried to moisture contents (MC) of less than 25%. Contact angles were measured on the tight side of the veneer after allowing the specimen to cool. The specimen was then returned to the oven, and the procedure repeated at different MCs.

Pine flakes were obtained from the Georgia-Pacific facility at Dudley, NC, and were moisture-equilibrated in plastic bags before use. The mill uses a high-temperature rotary dryer, to dry the furnish to 5% MC. Two presses were used. Small-scale work was done in an electrohydraulic press (Banerjee *et al.* 1998a) with platens of 14-cm diameter. The temperature of a stack of flakes (without added resin) was measured during pressing. The stack was placed inside a stainless steel bag fitted with inlet and outlet tubes. The top of the bag contacted a 200°C platen and the bottom was insulated with a dry felt. The temperature at the bottom would correspond to that at the center of a mat if both platens of the press were heated. The press closed in about 1 second at an applied pressure of 18 atm. The thermocouple was positioned in the mat at a distance of 2.2 mm (after pressing) from the top platen.

Larger-scale pressing was done at the Georgia-Pacific laboratory in Decatur, GA where 1.14 kg (dry basis) of wood was pressed at the temperature and pressure listed above to create 929-cm² x 1.9-cm boards.

Contact angle was measured with a First Ten Angstroms FTA 200 instrument. A piece of veneer was placed under a syringe that delivered a water drop of controlled volume. A computer-controlled camera captured images of the drop at predetermined time intervals; image analysis software was then used to determine the contact angle, volume, base-width, and height of the water drop as a function of time. The rate of water penetration was measured by noting the decrease in droplet volume over one second.

Results and Discussions

The contact angles of a water drop on veneer dried in the laboratory at 105, 150, and 175°C are shown in Figures 1-3, respectively. Drying to less than about 4% MC causes the contact angle to increase sharply. The rates of water penetration into veneer are listed in Table 1 and decrease with decreasing MC; bone-dry wood is almost impenetrable in the time frame of the measurement. The two sets of experiments show that surface hydrophobicity increases rapidly as the wood approaches dryness.

In order to relate these results to mill-dried specimens, contact angles of two commercially dried pieces of veneer were measured at ten different locations on the surfaces. Surprisingly, a value of 93° was obtained for both pieces ($\sigma=4^\circ, 6^\circ$), which corresponds to an MC of <1% on the basis of Figures 1-3. This leads to an anomaly since the wood was at 4% MC, which corresponds to a lower contact angle on the basis of Figures 1-3. It is possible that the disparity arises from differences in airflow and temperature between laboratory and field drying. The inlet temperature of the jet dryer in the mill was 200°C, and it is likely that surface dry-out occurred; i.e., the moisture was preferentially located in the interior of the sample, leaving the surface relatively dry. This type of behavior has been implicated before in high-temperature drying of flakes or particle (Banerjee *et al.* 1998b).

According to Hse (1972), a high contact angle (low moisture) is favorable in that it leads to good resin spread during pressing. On the other hand, drying to a higher moisture (MC>5%) is desirable from an environmental perspective since methanol and formaldehyde emissions rise sharply at lower MC (Otwell *et al.* 2000; Su *et al.* 1999). These compounds arise from the deg-

radiation of wood tissue, and at an MC of less than 5% evaporative cooling can no longer prevent the tissue temperature from rising to the point where degradation begins. It follows that a product with an overall MC of just over 5% and a dry surface layer would be attractive for both operational and environmental reasons. The field-dried veneer is not far from this situation. Raising the moisture content by a percentage point or so should provide environmental benefit as well while leaving glue spread relatively unaffected.

SEM images of flake surfaces dried at 105°C in the laboratory and processed commercially in a high-temperature triple pass rotary dryer are compared in Figure 4. The loss of detail in the field-dried flake is clearly evident and suggests that the surface was glazed to a greater degree, possibly with extractives and/or thermal breakdown products of the surface tissue. Clearly, heat reduces the surface porosity. This is consistent with the literature discussed earlier and with a report that drying temperature influences the surface properties of flakes (Plagemann *et al.* 1984). These micrographs are only a few of many taken, all of which showed a similar glaze for the field-dried flakes.

The contribution of extractives to surface hydrophobicity can be evaluated theoretically by computing the contact angle of water on a wood surface containing varying amounts of extractive. The algorithm (Banerjee and Etzler 1995) is based on the UNIFAC equation, an established chemical engineering method of estimating thermodynamic properties of mixtures (Poling *et al.* 2000). Contact angles of a wide range of polar and nonpolar liquids (including water) on polymer surfaces were calculated to within an average of 7° of measured values (Banerjee and Etzler 1995). For the present application, the solid surface was taken to be a mixture of glucose and oleic acid. The glucose represents cellulose, and oleic acid is a model for extractives. Increasing the oleic acid content on the surface increases the contact angle as shown in Figure 5. The estimated value of 56° for water on a pure cellulose surface corresponds quite well to the plateau values of about 60° in Figure 1. The angle rises to 73° as the presence of oleic acid increases on the surface. The Figure 5 curve is of the same overall shape as those in Figure 1, which we interpret as support for the role of extractives in influencing surface properties. However, the sharp rise in contact angle at low moistures seen in Figure 1 is absent in Figure 5, possibly because the Figure 1 rise reflects physical effects such as pore closure.

The above discussion indicates that drying at high temperature may increase surface hydrophobicity. To determine how this affects behavior during pressing, a stack of flakes was prepared by cutting a large flake into several pieces. An insulated thermocouple was attached to the top of the stack, which was placed on a 200°C hot plate. A 2-kg weight was applied to the stack, and the temperature was measured continuously. Temperature profiles of stacks of flakes at 5% MC dried in the laboratory (at 105°C) and in the field are compared in Figure 6. Note the slight break at about 100°C that occurs (reproducibly) *only* for the field-dried furnish. Since both sets of flakes were at the same MC, the difference likely originates from the manner in which the flakes were dried.

Next, temperature profiles within stacks of flakes were measured in the small press. Figure 7 illustrates a typical result for the temperature profiles for the pressing of both field- and laboratory-dried flakes. The temperatures rises smoothly for the low-moisture (2.8% MC) laboratory-dried flakes, but a break is observed at about 100°C for the higher-moisture (12.4% MC) laboratory-dried material and for the field-dried flakes, which were at 5% MC. The press closing period was much shorter than that of a commercial press. This was done to force extreme conditions. Press blows are infrequent, and it would be difficult to identify the factors that lead to press blows through a study conducted under typical operating conditions. The faster close leads to more rapid heat transfer and identifies situations that would be smoothed over and be more difficult to recognize in a more gradual operation. Indeed, the results from our larger press show no evidence of a break. The temperature profile of the core of a ¾" board during the pressing of field-dried flakes in the larger press is illustrated in Figure 8. The heating rate of this stack is much lower than that of the smaller one because of the thicker board used. For example, the core of a stack of flakes in the small press reached 120°C in 2 minutes; the larger unit required a much longer period. No temperature break is observed in Figure 8, probably because of differences in heat transfer properties as discussed above.

Numerous studies have detailed the temperature profile within a stack of flakes or a bed of particle during pressing. Heat transfer from the surface to the core is mainly convective through the movement of steam. As a result, the moisture near the face decreases at the onset of pressing, while that at the core rises (Bolton *et al.*, 1989). The temperature rise within the core and the internal pressure increases with increasing mat MC or platen temperature (Kamke and Casey 1988; Song and Ellis 1997).

The break in Figure 7 must represent evaporative cooling, which suggests that the water is unable to move easily towards the surface and evaporates in the vicinity of the thermocouple. The resulting build-up of pressure in the interior of the mat could lead to blows if the steam did not escape during pressing. Several mechanisms may be advanced to account for the break; perhaps the simplest involves moisture absorption by the flakes in the core. When the steam from the outer layers of the board moves to and condenses in the core, the water would be absorbed by the flakes if the flakes were sufficiently porous. However, the surface of the field-dried flakes is hydrophobic, as discussed above, and the condensed water would tend to form a film at the surface. When this moisture eventually evaporated it would give rise to local high pressure. The pressure increase for the laboratory-dried material would be lower, since its surface would be less hydrophobic and the moisture would have penetrated the furnish to a greater degree and be distributed over a larger volume. This suggests that the tendency towards delamination should increase with increasing dryer temperature.

In summary, both theoretical and experimental work suggests that the surface hydrophobicity of wood increases with increasing coverage of extractives. High-temperature drying promotes the exudation of extractives, which would inhibit water penetration into the furnish. Hence, much of the moisture driven from the outer layers of the mat dried at high temperature would be deposited on the surfaces of the wood in the core. This could lead to local overpressure when the water finally evaporated. In previous work we have shown that VOC emissions are lower when wood is dried at lower temperature. The present work demonstrates that low-temperature drying may also lead to operational benefit and establishes a link between drying practice and pressing performance.

Acknowledgements

This work was funded by the Electric Power Research Institute, Georgia-Pacific Corporation, International Paper, Ottertail Power, and the US Department of Energy.

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Table 1: Rate of water penetration into veneer	
MC (%)	rate (μL/s)
<i>105°C</i>	
10.1	6.0
6.2	2.1
3.9	2.4
<i>150°C</i>	
1.6	3.5
0.8	1.3
0.0	0.2
<i>175°C</i>	
3.1	2.8
0.8	0.5
0.0	0.0

Legends for Figures

Fig. 1 Contact angles of water on wood dried at 105°C.

Fig. 2 Contact angles of water on wood dried at 150°C.

Fig. 3 Contact angles of water on wood dried at 175°C.

Fig. 4 SEM images of flake surfaces dried at 105°C (left) and in the field (right).

Fig. 5 Dependence of the contact angle of water on a surface constructed from glucose and oleic acid.

Fig. 6 Temperature profile for a 2.5-mm stack of 3 flakes.

Fig. 7 Temperature profiles from pine flakes. Field-dried: solid line. Lab-dried to 2.8% MC (upper dashed curve) and 12.4% MC (lower dashed curve).

Fig. 8 Board core temperature during pressing.

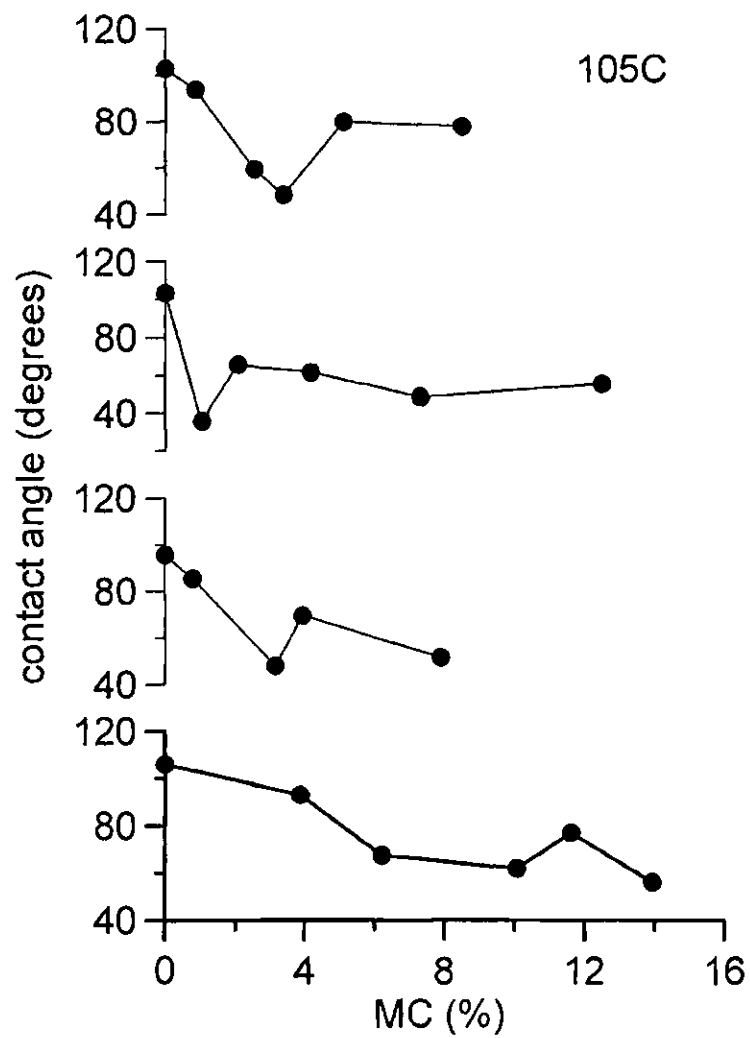


Fig. 1. Contact angles of water on wood dried at 105°C.

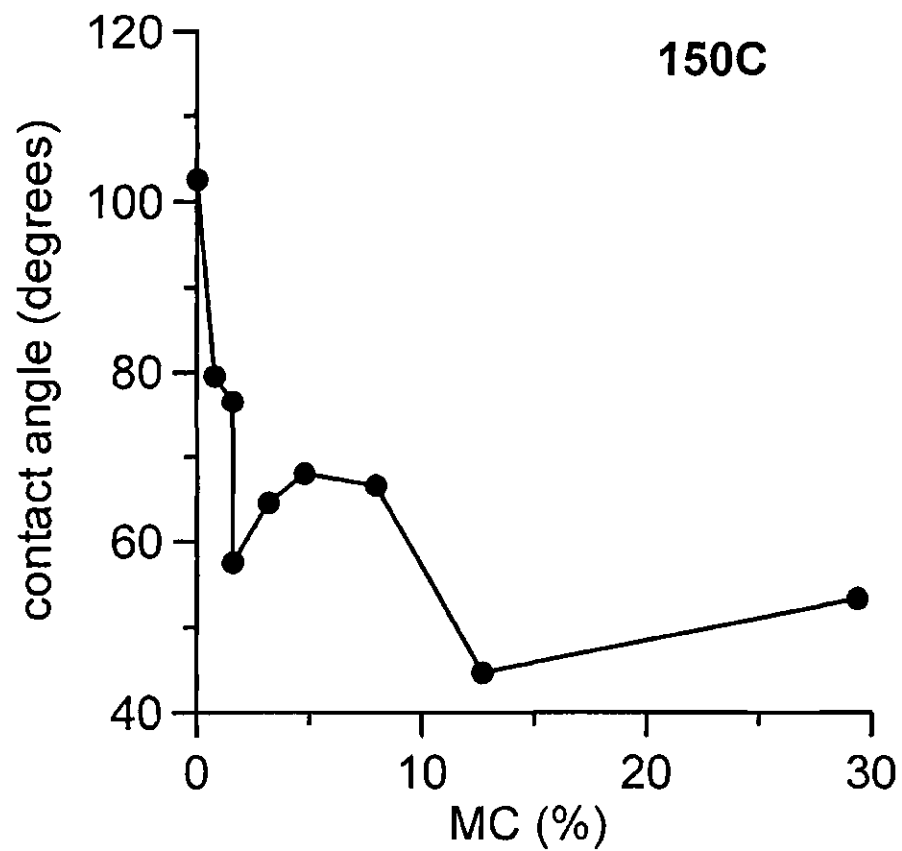


Fig. 2. Contact angles of water on wood dried at 150°C.

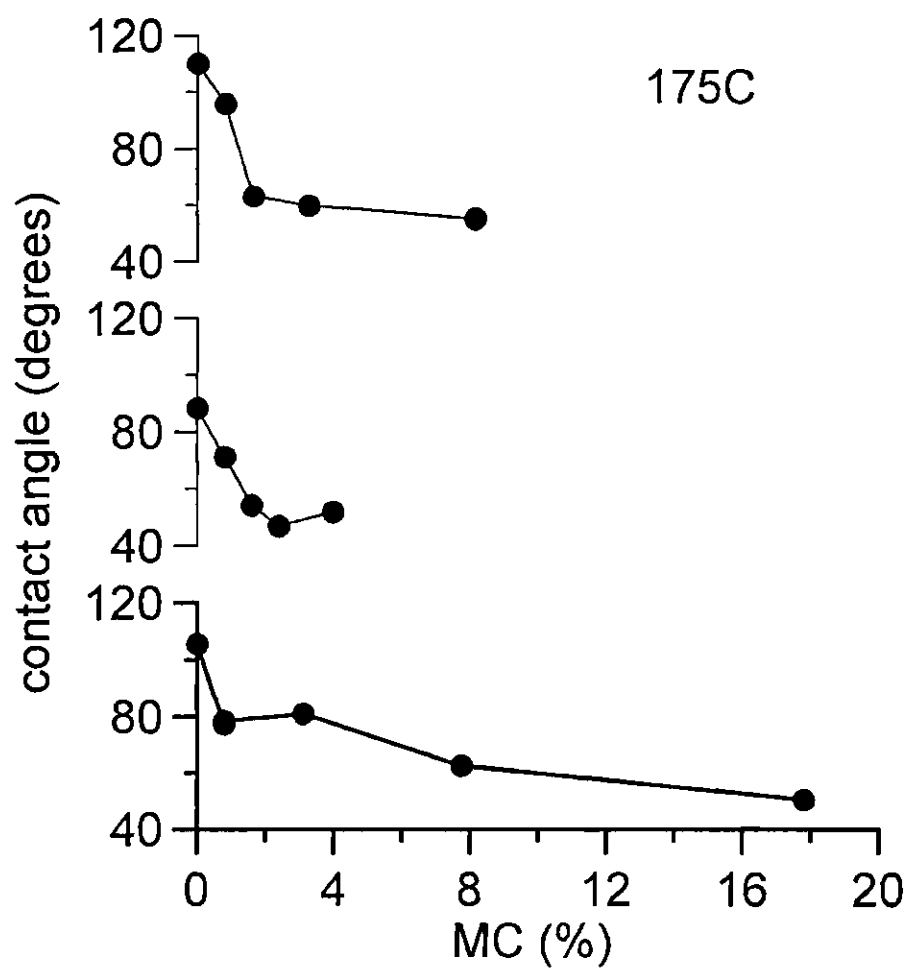


Fig. 3. Contact angles of water on wood dried at 175°C.

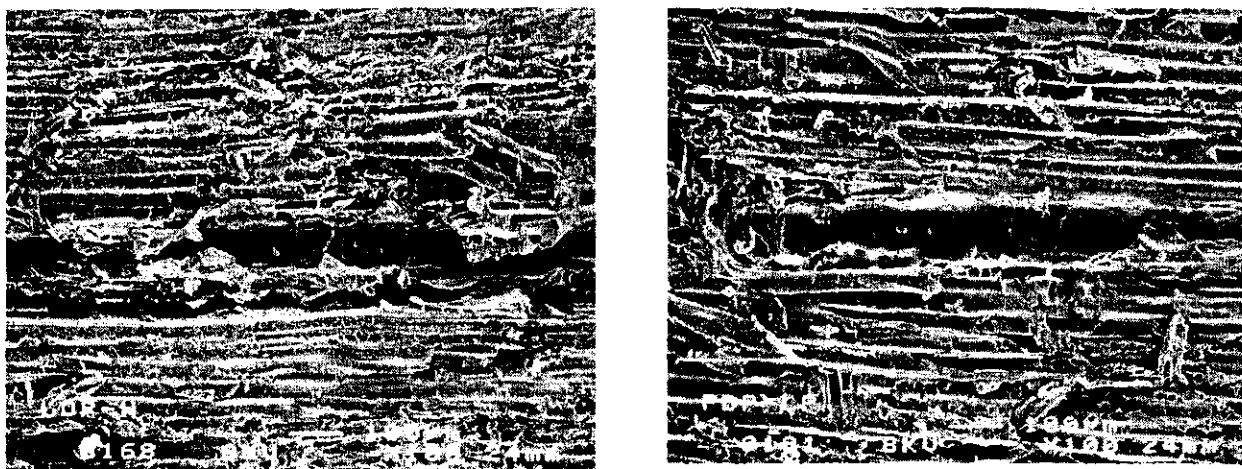


Fig. 4. SEM images of flake surfaces dried at 105°C (left) and in the field (right).

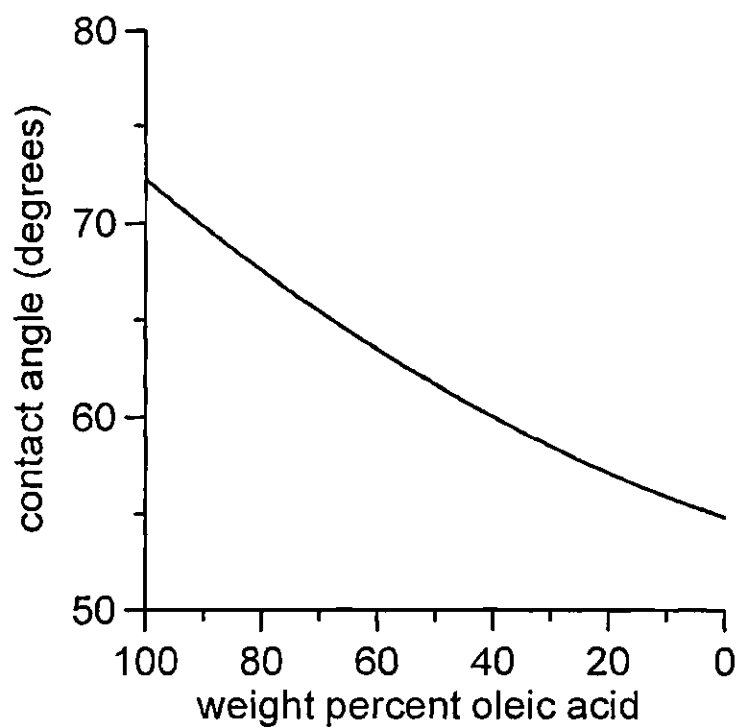


Fig. 5. Dependence of the contact angle of water on a surface constructed from glucose and oleic acid.

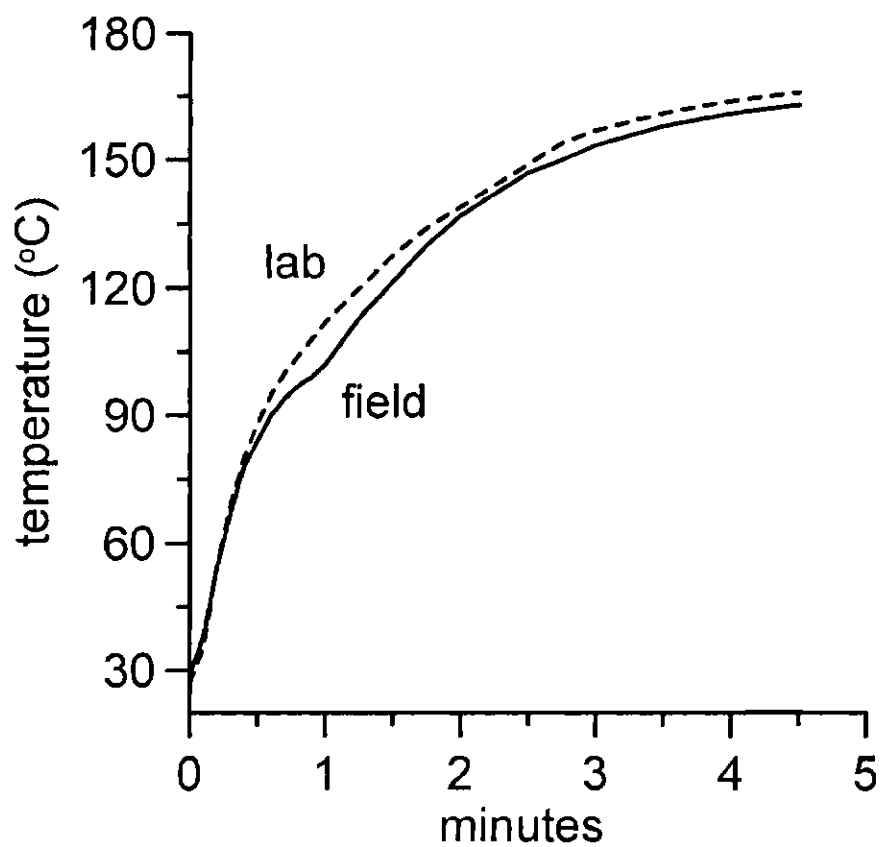


Fig. 6. Temperature profile for a 2.5-mm stack of 3 flakes.

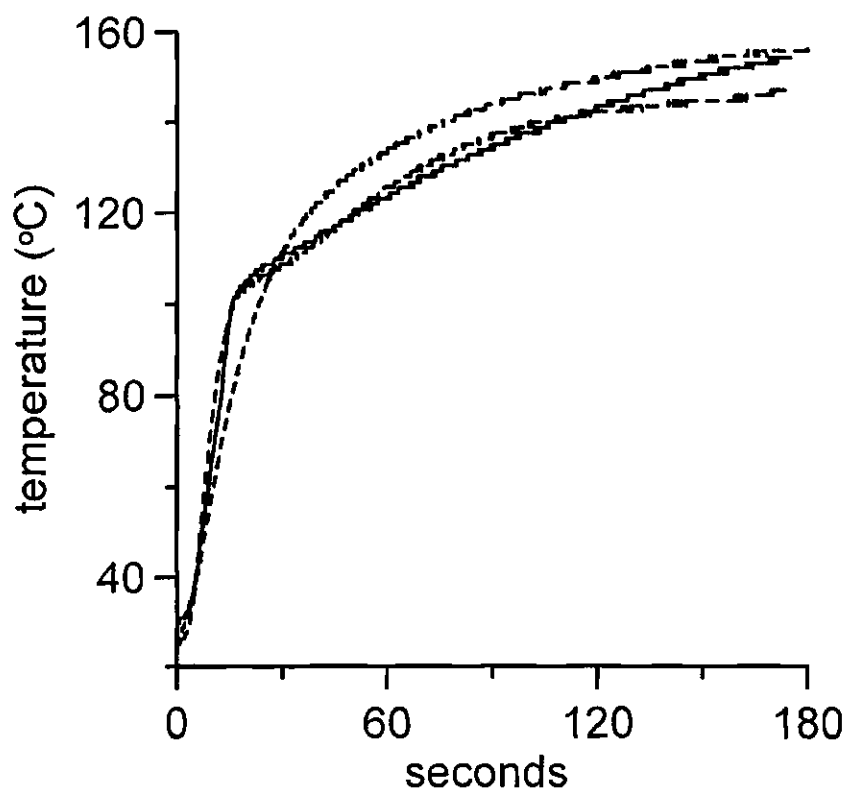


Fig. 7. Temperature profiles from pine flakes. Field-dried: solid line. Lab-dried to 2.8% MC (upper dashed curve) and 12.4% MC (lower dashed curve)

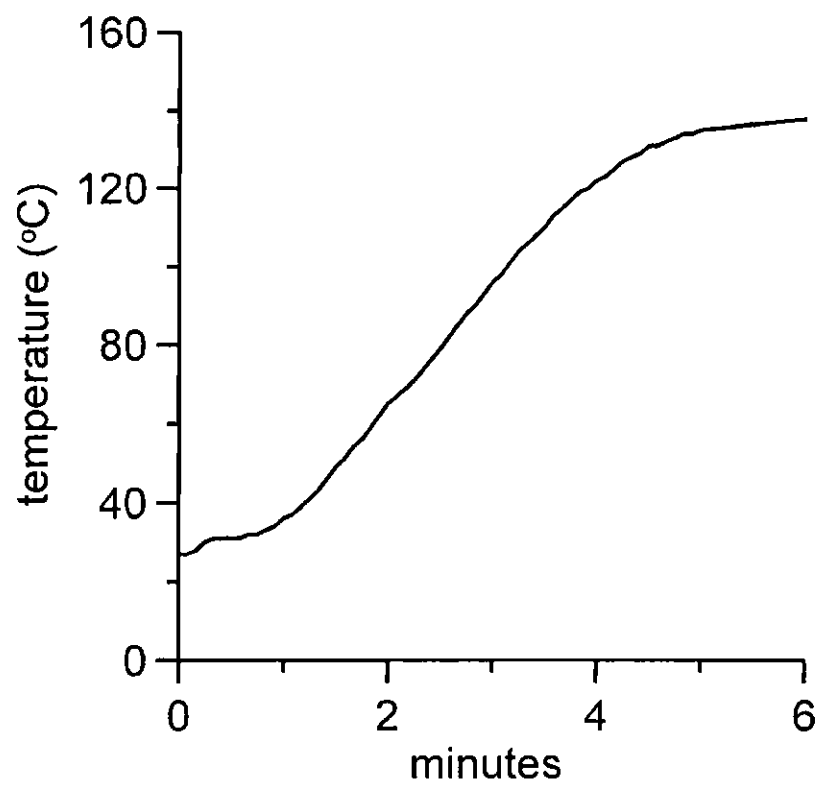


Fig. 8. Board core temperature during pressing.